Inelastic Neutron Scattering: Science and Instrumentation

Collin Broholm*
Johns Hopkins University and NIST Center for Neutron Research

- What we learn from INS
- Current instrumentation
- Future instrumentation
- Conclusions

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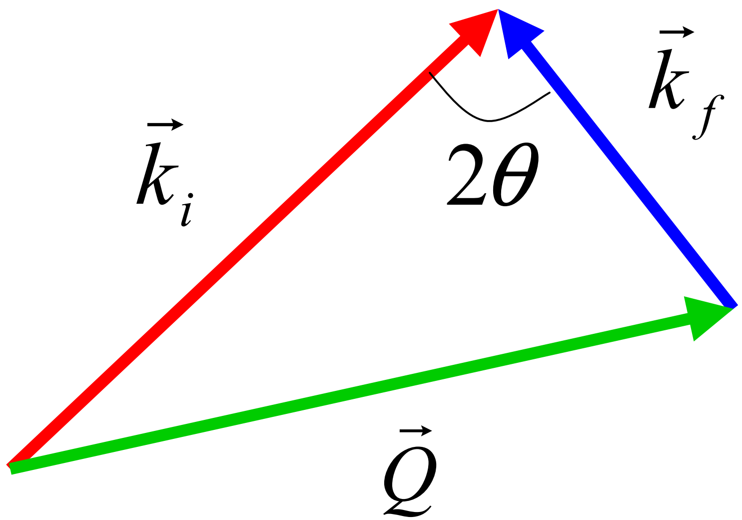
Inelastic Neutron Scattering



$$\vec{Q} = \vec{k}_i - \vec{k}_f$$

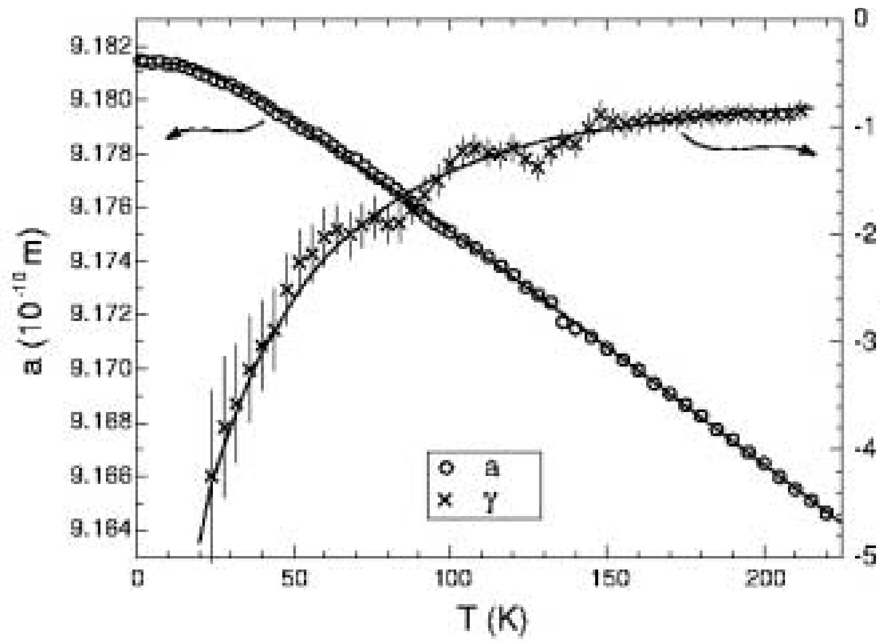
$$\hbar\omega = E_i - E_f$$

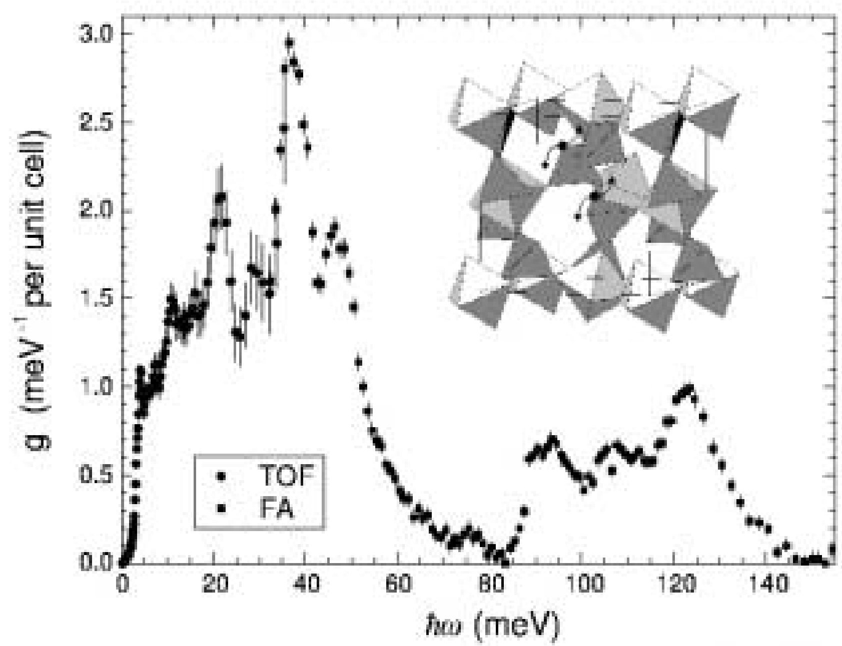
The neutron has an ideal dispersion relation for probing dynamics of condensed matter through inelastic scattering:

$$E = \frac{(\hbar k)^2}{2m} = 2.0717 \text{ meV}\dot{\text{A}}^2\ k^2$$

Lattice dynamics in a material that shrinks on heating

Ernst et al Nature (1998)





ZrW_2O_8 is being used to create composites without thermal contraction for fiber optical gratings in telecommunication systems

Neutron Sources in 1999

CW Sources	facilities	Total Flux (10^{15} n/cm^2/s)	Total Average flux (10^{15} n/cm^2/s)
Asia	3	1.0	0.6
Europe	6	2.2	1.4
USA	4	2.5	1.1

Pulsed Sources	facilities	Total Power (kW)	Total Average Power (kW)
Asia	1	3	1
Europe	1	160	77
USA	2	86	56

Energy resolution, Science, and Instrumentation

<table>
<tr><th>δE</th><th>Science</th><th>Instruments</th></tr>
<tr><td><0.1 μeV</td><td>Polymers,
Glasses</td><td>Spin Echo</td></tr>
<tr><td>0.1-5 μeV</td><td>Molecular tunelling, Bio-systems</td><td>Perfect crystal Backscattering</td></tr>
<tr><td>5-25 μeV</td><td rowspan="2">Critical dynamics, magnetic excitations below Zeeman energy</td><td>PG/MICA backscattering</td></tr>
<tr><td>25-100 μeV</td><td rowspan="2">Cold TAS, Direct DIsc TOF</td></tr>
<tr><td>0.1-0.5 meV</td><td rowspan="2">Phonons and
Spin waves</td></tr>
<tr><td>0.5-5 meV</td><td>Thermal TAS, Direct Chopper TOF</td></tr>
<tr><td>>5 meV</td><td>Electrons in Oxides
molecular vibrations</td><td>Hot TAS, Direct chopper TOF,
Filter difference</td></tr>
</table>

Instrumentation at CW sources in 1999

	dE < 0.1 μeV #	Eq. Av. core flux ($10^5 n/cm^2/s$)	0.1-5 μeV #	Eq. Av. core flux ($10^5 n/cm^2/s$)	5-25 μeV #	Eq. Av. core flux ($10^5 n/cm^2/s$)	25-100 μeV #	Eq. Av. core flux ($10^5 n/cm^2/s$)
Europe	6	2.2	3	1.6	6	1.2	9	1.1
USA	1	0.29	1	0.29	1	0.10	3	0.40

	0.1-0.5 meV #	Eq. Av. core flux ($10^5 n/cm^2/s$)	0.5-5 meV #	Eq. Av. core flux ($10^5 n/cm^2/s$)	dE > 5 meV #	Eq. Av. core flux ($10^5 n/cm^2/s$)
Europe	17	3.1	11	4.4	1	0.74
USA	3	0.40	8	3.6	1	0.15

On average US capability falls short by a factor 3

Instrumentation at pulsed sources in 1999

	dE<0.1 μeV Eq. Av. # power (kW)		0.1-5 μeV Eq. Av. # power (kW)		5-25 μeV Eq. Av. # power (kW)		25-100 μeV Eq. Av. # power (kW)	
Europe	0	0	0	0	1	.78	0	0
USA	0	0	0	0	0	0	0	0

	0.1-0.5 meV Eq. Av. # power (kW)		0.5-5 meV Eq. Av. # power (kW)		dE>5 meV Eq. Av. # power (kW)	
Europe	1	38	5	190	5	230
USA	3	55	5	58	3	3.9

On average US capability falls short by a factor 5

Neutron Sources in 2009

CW Sources	facilities	Total Flux (10^{15} $n/cm^2/s$)	Total Average flux (10^{15} $n/cm^2/s$)
Asia	3	2.6	1.6
Europe	6	3.0	1.9
USA	4	2.5	1.8

Pulsed Sources	facilities	Total Power (kW)	Total Average Power (kW)
Asia	1	600	370
Europe	2	500	273
USA	2	1200	800

Future Neutron Spectrometers

- Technical progress:
  - Greater raw source flux
  - Optimize incident solid angle
  - Detection system analyzes scattered neutrons simultaneously
  - Better software to optimize experiment and view data
- Scientific Opportunities
  - Spectroscopy under extreme conditions of T, H, P...
  - Spectroscopy of thin films and very small samples
  - Dynamics as a function of time following perturbation
  - Spectroscopy versus composition
  - INS as a first probe of new materials

US Neutron Spectrometers planned for next decade

- NIST Center for Neutron Research:
  - Enhanced Cold TAS. 100 times more efficient than conventional TAS.
  - 2 Modernized Thermal TAS with focusing optics.
- LANSCE at LANL
  - HELIOS: High intensity Chopper spectrometer.
  - HERMES: PG(002) high resolution Back-scattering.
  - IN500: Direct TOF with 100 times the efficiency of current IN5
- SNS (1MW new spallation source)
  - Approximately 4 modernized TOF spectrometers each at least 6 times better than similar current instrumentation.
  - A second target station would allow optimized high resolution. instrumentation of which we have too little at present.
- HFIR at ORNL
  - Modernized cold neutron TAS.

Conclusions

- INS is necessary to understand condensed matter and develop materials that can support continued technological progress.
- The US has fallen far behind in the area of INS instrumentation
- Investment in instrumentation for existing and new facilities is essential to make best use of the resources required to build and operate facilities
- Education of scientists who can use INS is of paramount importance as we ramp up instrumentation in this area.